Claims

1. A magnetic position sensor for measuring one of a linear position and an angular position of a device, the sensor comprising:

a linear array of galvanomagnetic sensing elements fixedly mountable adjacent the device;

a target connectable to the device such that the target moves adjacent a surface of the linear array in response to movement of the device, the target shaped so that a magnetic flux density curve resulting from excitation of the sensing elements includes at least one of a peak and a valley;

a first circuit for exciting each of the sensing elements; and

a second circuit for measuring a magnetic flux density value at each of the sensing elements, wherein each magnetic flux density value is associated with the magnetic flux density curve and wherein at least one of a maximum of the peak and a minimum of the valley indicates one of the linear position and the angular position of the device.

2. The magnetic position sensor according to claim 1 wherein each of the sensing elements comprises one of a Hall element and a magnetoresistive element.

3. The magnetic position sensor according to claim 1 wherein the target is one of a magnetic tooth and a magnetic slot.

4. The magnetic position sensor according to claim 1 wherein the target comprises one of two magnetic teeth separated by a target spacing and two magnetic slots separated by the target spacing; and wherein the target spacing is one of equal to and less than half of a distance between a first galvanomagnetic sensing element and a last galvanomagnetic sensing element of the linear array.

5. The magnetic position sensor according to claim 1 wherein the target is operably positionable at a fixed angle α with respect to a direction of displacement of the target upon movement of the device such that a range of the sensor is equal to a distance between a first galvanomagnetic sensing element and a last galvanomagnetic sensing element of the linear array divided by sin α.

6. The magnetic position sensor according to claim 1 wherein the target is operably positionable to move normal to a length of the linear array in response to movement of the device.

7. The magnetic position sensor according to claim 1 wherein the first circuit comprises at least one of a constant voltage source and a constant current source.

8. The magnetic position sensor according to claim 7 wherein the second circuit comprises a circuit for measuring a voltage potential at each of the sensing elements, wherein each voltage potential represents a magnetic flux density value of the magnetic flux density curve.

9. The magnetic position sensor according to claim 1, further comprising:

side offset compensation for compensating for errors in measurement of linear position using the target.

10. The magnetic position sensor according to claim 1 wherein the target is one of a spiral magnetic tooth and a spiral magnetic slot rotatable about an axis.

11. The magnetic position sensor according to claim 10, further comprising:

eccentricity compensation means for compensating for eccentricity-related errors in a measurement of angular position using the target.

12. The magnetic position sensor according to claim 1 wherein the target comprises a magnetic tooth in the form of a spiral magnetic strip supported by a non-magnetic disk, the spiral magnetic strip starting at a first point a first radial distance from a center of the disk and continuing around a circumference of the non-magnetic disk along a path having a continuously-increasing radius until the strip reaches a second point having a second radial distance from the center of the disk; and wherein the non-magnetic disk is mountable on a shaft rotatable with movement of the device.

13. The magnetic position sensor according to claim 12 wherein each location of the spiral magnetic strip along a length of the linear array corresponds to a unique angle of rotation β of the shaft according to the formula $R(\beta) = r + \beta (R-r) / 360°$, wherein $R(\beta)$ is a radius of the spiral magnetic strip at the unique angle of rotation β, R is a larger of the first radial distance and the second radial distance, and r is the other of the first radial distance and the second radial distance.

14. The magnetic position sensor according to claim 12, further comprising:

a second magnetic tooth in the form of an annular magnetic strip supported by the non-magnetic disk, the annular magnetic strip one of radially inside the spiral magnetic strip and radially outside the spiral magnetic strip, and the annular magnetic strip concentric with the non-magnetic disk.

15. The magnetic position sensor according to claim 14, further comprising:

means for subtracting a location of a second peak of a magnetic flux density curve resulting from the annular magnetic strip from a location of the peak of the magnetic flux density curve resulting from the spiral magnetic strip.

16. The magnetic position sensor according to claim 1 wherein the second circuit further comprises means for fitting the magnetic flux density value associated with certain of the galvanomagnetic sensing elements to a function having at least one of a peak curve and a valley curve, and wherein at least one of a location of a minimum and a location of a maximum of the function indicates one of the linear position and the angular position of the device.

17. The magnetic position sensor according to claim 1, further comprising:

means for determining at least one of the maximum of the peak and the minimum of the valley using magnetic flux density values measured at certain of the sensing elements.

18. The magnetic position sensor according to claim 17 wherein certain of the sensing elements includes a set of three sequential sensing elements numbered j_1, j_2, j_3 respectively having three sequential magnetic flux density values V_1, V_2, V_3, one of the three sequential magnetic flux density values V_1, V_2, V_3 being one of a highest and a lowest of the magnetic flux density values measured by the second circuit; and wherein a position of the target relative to array element numbers is equal to $\left(\frac{j_1^2(V_3 - V_2) + j_2^2(V_1 - V_3) + j_3^2(V_2 - V_1)}{j_1(V_3 - V_2) + j_2(V_1 - V_3) + j_3(V_2 - V_1)}\right)$.

19. The magnetic position sensor according to claim 17 wherein certain of the sensing elements includes a first set of three sequential sensing elements numbered j_1, j_2, j_3 respectively having three sequential magnetic flux density values V_1, V_2, V_3, one of the three sequential magnetic flux density values V_1, V_2, V_3 being one of a highest and a lowest of the magnetic flux density values measured by the

second circuit; and wherein certain of the sensing elements includes a second set of three sequential sensing elements numbered j_4, j_5, j_6 respectively having three sequential magnetic flux density values V_4, V_5, V_6, one of the three sequential magnetic flux density values V_4, V_5, V_6 also being the one of the highest and the lowest of the magnetic flux density values measured by the second circuit; and wherein a position of the target relative to array element numbers is equal to an average of

$$\left(\frac{j_1^2(V_3 - V_2) + j_2^2(V_1 - V_3) + j_3^2(V_2 - V_1)}{j_1(V_3 - V_2) + j_2(V_1 - V_3) + j_3(V_2 - V_1)}\right) \text{ plus } \left(\frac{j_4^2(V_6 - V_5) + j_5^2(V_4 - V_6) + j_6^2(V_5 - V_4)}{j_4(V_6 - V_5) + j_5(V_4 - V_6) + j_6(V_5 - V_4)}\right).$$

20. The magnetic position sensor according to claim 1 wherein the target further comprises one of two spaced magnetic teeth and two spaced magnetic slots.

21. The magnetic position sensor according to claim 20 wherein the target comprises the two spaced magnetic teeth, the sensor further comprising:

means for determining a location of a maximum of a first peak of the magnetic flux density curve, the determining means operable to detect one of a presence and an absence of a minimum of the magnetic flux density curve; and wherein when the presence of the minimum is detected, the location of the maximum and the location of the minimum indicate the linear position of the device; and wherein when the absence of the minimum is detected, the location of the maximum and the absence of the minimum indicates the linear position of the device.

22. The magnetic position sensor according to claim 20 wherein the target comprises two spaced magnetic slots, the sensor further comprising:

means for determining a location of a minimum of a first valley of the magnetic flux density curve, the determining means operable to detect one of a presence and an absence of a maximum of the magnetic flux density curve; and wherein when the presence of the maximum is detected, the location of the minimum and the location of the maximum indicate the linear position of the device; and

wherein when the absence of the maximum is detected, the location of the minimum and the absence of the maximum indicates the linear position of the device.

23. A method of measuring one of a linear position and an angular position of a device, comprising the steps of:

fixedly mounting a linear array of galvanomagnetic sensing elements adjacent the device;

connecting a target to the device such that the target moves adjacent a surface of the linear array in response to movement of the device, the target shaped so that a magnetic flux density curve resulting from excitation of the sensing elements includes at least one of a peak and a valley;

exciting each of the sensing elements; and

measuring a magnetic flux density value at each of the sensing elements, wherein each magnetic flux density value is associated with the magnetic flux density curve and wherein at least one of a maximum of the peak and a minimum of the valley indicates one of the linear position and the angular position of the device.

24. The method according to claim 23 wherein the fixedly mounting step further comprises the step of stationarily mounting the linear array adjacent the device such that the linear array does not move with movement of the device.

25. The method according to claim 23 wherein the connecting step further comprises the step of connecting one of a magnetic mount and a non-magnetic mount to the device wherein the target is one of a slot in the magnetic mount and a magnetic strip embedded in the non-magnetic mount.

26. The method according to claim 23, further comprising the step of:

rotating the target about an axis in response to movement of the device wherein the target is one of a spiral magnetic tooth and a spiral magnetic slot.

27. The method according to claim 26, further comprising the step of:

compensating for eccentricity-related errors in a measurement of angular position using the target.

28. The method according to claim 23 wherein the connecting step further comprises the step of mounting an annular disk on a shaft rotatable with movement of the device, wherein the target is a spiral magnetic strip supported by a non-magnetic disk, the spiral magnetic strip starting at a first point a first radial distance from a center of the disk and continuing around a circumference of the non-magnetic disk along a path having a continuously-increasing radius until the strip reaches a second point having a second radial distance from the center of the disk.

29. The method according to claim 28 wherein the fixedly mounting step further comprises the step of stationarily mounting the linear array adjacent the device and facing the surface of the non-magnetic disk such that, upon rotation of the shaft, each location of the spiral magnetic strip along a length of the linear array corresponds to a unique angle of rotation β according to the formula $R(\beta) = r + \beta\,(R-r) / 360°$, wherein $R(\beta)$ is a radius of the spiral magnetic strip target at the unique angle of rotation β, R is a larger of the first radial distance and the second radial distance, and r is the other of the first radial distance and the second radial distance.

30. The method according to claim 28 wherein an annular magnetic strip is supported by the non-magnetic disk one of radially inside the spiral magnetic strip and radially outside the spiral magnetic strip, the annular magnetic strip concentric with the non-magnetic disk.

31. The method according to claim 30, further comprising the step of:

subtracting a position of a second peak of a magnetic flux density curve resulting from the annular magnetic strip from a position of the maximum of the peak of the magnetic flux density curve resulting from the spiral magnetic strip.

32. The method according to claim 23 wherein the connecting step further comprises the step of positioning the target at a fixed angle α with respect to a direction of displacement of the target upon movement of the device such that a range of the sensor is equal to a distance between a first galvanomagnetic sensing element and a last galvanomagnetic sensing element of the linear array divided by sin α.

33. The method according to claim 23 wherein the connecting step further comprises the step of positioning the target such that target moves normal to a length of the linear array upon movement of the device.

34. The method according to claim 23 wherein the exciting step further comprises the step of applying one of a constant current and a constant voltage to each of the sensing elements.

35. The method according to claim 23 wherein the measuring step further comprises the step of measuring a voltage across each of the sensing elements; and wherein each voltage represents a magnetic flux density value.

36. The method according to claim 23, further comprising the steps of:

fitting certain of the magnetic flux density values measured in the measuring step to a function having at least one of a peak curve and a valley curve; and

computing at least one of a location of a maximum of the function and a location of a minimum of the function.

37. The method according to claim 23, further comprising the step of:

compensating for errors in a measurement of linear position using side offset compensation.

38. The method according to claim 23, further comprising the step of:

developing the magnetic flux density curve using magnetic flux density values measured at certain of the sensing elements.

39. The method according to claim 23, further comprising the step of:

determining at least one of a location of the maximum of the peak and a location of the minimum of the valley using magnetic flux density values measured at certain of the sensing elements.

40. The method according to claim 23, further comprising the steps of:

sequentially numbering each of the sensing elements of the linear array with an array element number;

finding a set of three sequential sensing elements numbered j_1, j_2, j_3 respectively having three sequential magnetic flux density values V_1, V_2, V_3, one of the three sequential magnetic flux density values V_1, V_2, V_3 being one of a highest and a lowest of the magnetic flux density values measured in the measuring step; and

calculating a position of the target relative to array element numbers assigned in the sequentially numbering step according to the formula

$$\left(\frac{j_1^2(V_3 - V_2) + j_2^2(V_1 - V_3) + j_3^2(V_2 - V_1)}{j_1(V_3 - V_2) + j_2(V_1 - V_3) + j_3(V_2 - V_1)}\right).$$

41. The method according to claim 40, further comprising the step of:

multiplying the position by a spacing between adjacent sensing elements of the linear array, wherein a result of the multiplying step is a location of the target relative to a first galvanomagnetic sensing element of the sensing elements.

42. The method according to claim 23, further comprising the steps of:

sequentially numbering each of the sensing elements of the linear array with an array element number;

finding a first set of three sequential sensing elements numbered j_1, j_2, j_3 respectively having three sequential magnetic flux density values V_1, V_2, V_3, one of the three sequential magnetic flux density values V_1, V_2, V_3 being one of a highest and a lowest of the magnetic flux density values measured in the measuring step;

finding a second set of three sequential sensing elements numbered j_4, j_5, j_6 respectively having three sequential magnetic flux density values V_4, V_5, V_6, one of the three sequential magnetic flux density values V_4, V_5, V_6 also being the one of the highest and the lowest of the magnetic flux density values measured in the measuring step; and

calculating a position of the target relative to the array element numbers assigned in the numbering step, wherein the position is equal to an average of

$$\left(\frac{j_1^2(V_3 - V_2) + j_2^2(V_1 - V_3) + j_3^2(V_2 - V_1)}{j_1(V_3 - V_2) + j_2(V_1 - V_3) + j_3(V_2 - V_1)}\right) \text{ plus } \left(\frac{j_4^2(V_6 - V_5) + j_5^2(V_4 - V_6) + j_6^2(V_5 - V_4)}{j_4(V_6 - V_5) + j_5(V_4 - V_6) + j_6(V_5 - V_4)}\right).$$

43. The method according to claim 23 wherein the connecting step further comprises the step of connecting one of a magnetic mount and a non-magnetic mount to the device wherein the target is one of at least two spaced slots in the

magnetic mount and at least two spaced magnetic strips embedded in the non-magnetic mount.

44. The method according to claim 23 wherein the target comprises two spaced magnetic teeth, the method further comprising the steps of:

determining a location of a maximum of a first peak of the magnetic flux density curve;

detecting one of a presence and an absence of a minimum of the magnetic flux density curve;

locating the linear position of the device using the location of the maximum and a location of the minimum when the detecting step indicates the presence of the minimum; and

locating the linear position of the device using the location of the maximum and the absence of the minimum when the detecting step indicates the absence of the minimum.

45. The method according to claim 23 wherein the target comprises two spaced magnetic slots, the method further comprising the steps of:

determining a location of a minimum of a first valley of the magnetic flux density curve;

detecting one of a presence and an absence of a maximum of the magnetic flux density curve;

locating the linear position of the device using the location of the minimum and a location of the maximum when the detecting step indicates the presence of the maximum; and

locating the linear position of the device using the location of the minimum and the absence of the maximum when the detecting step indicates the absence of the maximum.